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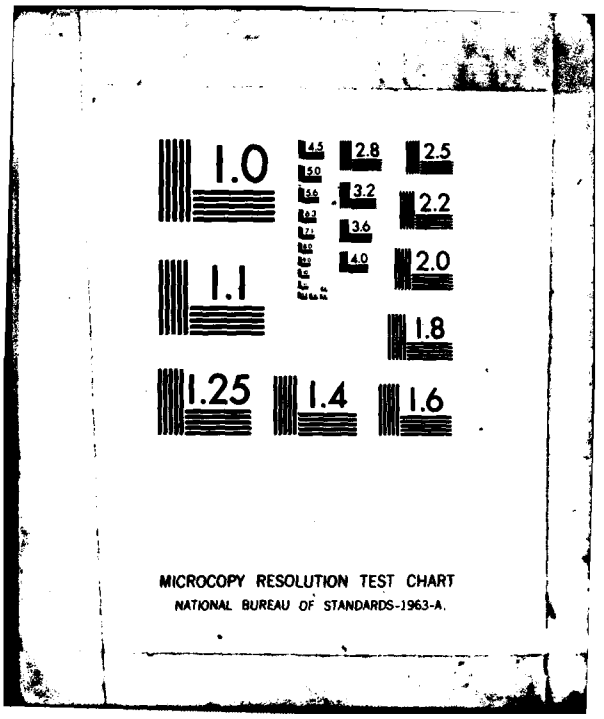
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Edward L. Ginzton Laboratory
W. W. Hansen Laboratories of Physics
Stanford University
Stanford, California

ACOUSTIC MICROSCOPY AT CRYOGENIC TEMPERATURES

Summary Report

Index of Research Performed from July 1977 - June 1982

Task NR 384-924

Contract N00014-77-C-0412

G. L. Report No. 3435

June 1982

ACOUSTIC MICROSCOPY AT CRYOGENIC TEMPERATURES

Contract No. N00014-77-C-0412

Summary Report

Some years ago it became evident that research devoted to acoustic microscopy at cryogenic temperatures would allow us to realize the full potential of this new instrument and extend the resolving power beyond the limits imposed by the room temperature microscope. In 1977, the Office of Naval Research agreed to fund such a program at Stanford University. It was to be directed toward an increase in our understanding of the propagation of acoustic waves in cryogenic fluids and the physics of imaging with these waves. We were to concern ourselves with the sub-micron region.

This short report includes a compilation of the written materials and presentations that have resulted from this program. The work of Dr. Logan Hargrove, who has guided the program since its inception, is deeply appreciated.

Cryogenic fluids are attractive for propagation of acoustic waves with short wavelengths since the velocity of sound is low and the attenuation is moderate. Much of our work has been done with liquid argon and liquid nitrogen. High quality acoustic images have been recorded in these media and it has been shown that an operating instrument can be a rather simple device.

One recent achievement is the demonstration that operation in the non-linear region can improve the resolution in a significant way.

During the period of this research, it has become increasingly clear that the ultimate resolution - perhaps rivaling that of the Scanning

Electron Microscope, and certainly exceeding that of the optical microscope - will be achieved in liquid helium. Our first work was done in ^4He at 1.95^oK where we demonstrated that quality images could be recorded. But, the tantalizing prospect of helium at a temperature of 0.1^oK attracts us and that is where we will place the emphasis from this point on.

The acoustic absorption decreases as the fourth power of temperature in the range below 0.5^oK. At 0.1^oK the acoustic absorption at microwave frequencies is no longer an important property in the imaging instrument. It will be dominated by other factors such as the smoothness of the lens surface and the non-linear behavior of the liquid itself.

The most recent result - coming at the conclusion of this program period - is a demonstration of an operating instrument in ^4He - cooled to a temperature of 0.1^oK. The wavelength was near 3000 $\mathring{A}$ and the signal-to-noise ratio was sufficient to record acceptable images.

We find that this program spans an interesting period in cryogenic acoustic microscopy. It began with the first images in cryogenic fluids - argon and nitrogen. It proceeded through a period of investigating properties of helium at ultralow temperatures and it now ends with a prototype instrument that is capable of generating images at 0.1^oK where the liquid absorption has decreased to a negligible value. It suggests that we are on the threshold of a new era for imaging in the sub-micron region of the microscopic world.

Reports

Semiannual Report, 1 July 1977 - 1 January 1978 (G.L. Report No. 2773)

Annual Report, 1 July 1977 - 30 June 1978 (G.L. Report No. 2865) (AD A060391)

Semiannual Report, 1 July 1978 - 1 January 1979 (G.L. Report No. 2921)

Annual Report, 1 July 1978 - 30 June 1979 (G.L. Report No. 3008) (AD A074502)

Semiannual Report, 1 July 1979 - 1 January 1980 (G.L. Report No. 3083)

Annual Report, 1 July 1979 - 30 June 1980 (G.L. Report No. 3149) (AD A087677)

Semiannual Report, 1 July 1980 - 1 January 1981 (G.L. Report No. 3241)

Annual Report, 1 July 1980 - 30 June 1981 (G.L. Report No. 3369) (AD 109271)

Semiannual Report, 1 January 1981 - 1 July 1981 (G.L. Report No. 3336)

Semiannual Report, 1 July 1981 - 1 January 1982 (G.L. Report No. 3388)

Publications

C. F. Quate, "Ultrasonic Imaging", in Electronic Imaging, Rank Prize Funds International Symposium, London, England, September 1978, P. Schagen and T. McLean, Eds. (Academic Press Ltd, 1979) pp. 365-393.

J. Heiserman, D. Rugar and C. F. Quate, "Cryogenic Acoustic Microscopy", J. Acoust. Soc. Am. 67, 1629-1637 (May 1980).

C. F. Quate, "Microwaves, Acoustics and Scanning Microscopy", in Scanned Image Microscopy, Rank Prize Funds International Symposium, London, England, September 1980, E. A. Ash, ed. (Academic Press Ltd, 1980) pp. 23-55.

J. Heiserman, "Cryogenic Acoustic Microscopy", in Scanned Image Microscopy, Rank Prize Funds International Symposium, London, England, September 1980, E. A. Ash, ed. (Academic Press Ltd, 1980) pp. 71-96.

D. Rugar, J. Heiserman, S. Minden and C. F. Quate, "Acoustic Microscopy of Human Metaphase Chromosomes", J. of Microscopy, 120, 193-199 (November 1980).

C. F. Quate, "The Acoustic Microscope: a Concept of Microscopy using Waves of Sound", Naval Research Reviews, Office of Naval Research, Vol. XXXIII, No. 1, 33, 24-32 (Fall-Winter 1980-81).

J. Heiserman, "Acoustic Measurements in Superfluid Helium", Section 8 in Methods of Experimental Physics, Vol. 19 (Ultrasonics) P. Edmonds, ed. (Academic Press, 1981) pp. 413-453.

Publications, continued

C. F. Quate - 1981 Science Year, Annual Supplement of the World Book Encyclopedia. Photograph supplied of chick embryo fibroblasts comparing optical and acoustic images.

J. Heiserman, "Cryogenic Acoustic Microscopy: the Search for Ultrahigh Resolution using Cryogenic Liquids". To be published in Physica (North-Holland Publishing Company).

J. Heiserman, "Thermal Grounding of a Transmission Line in a Dilution Refrigerator". To be published in Cryogenics.

Meetings

C. F. Quate - Invited paper, Rank Prize Funds International Symposium on "Electronic Imaging", September 13, 1978, Royal Society, London, England. Abstract entitled "Ultrasonic Imaging".

C. F. Quate - Invited talk, Optical Society of America, November 1, 1978, San Francisco, California. Abstract entitled "The Scanning Acoustic Microscope".

J. Heiserman and D. Rugar - 96th Meeting of the Acoustical Society of America, 27 November-1 December, 1978, Honolulu, Hawaii. Abstract entitled "Acoustic Microscopy at Cryogenic Temperatures", J. Acoust. Soc. Am. 64, Suppl. 1, X2.

C. F. Quate - Invited paper, American Physical Society, March 19, 1979, Chicago, Illinois. Abstract entitled "The Mechanically Scanned Acoustic Microscope".

C. F. Quate - Invited talk, 50th Anniversary Meeting, Acoustical Society of America, June 13, 1979, Cambridge, Mass. Abstract entitled "New Results in Ultrasonic Microscopy".

J. Heiserman - Invited talk, Rank Prize Funds International Symposium on "Scanned Image Microscopy", September 22-24, 1980, Royal Society, London, England. Paper entitled "Cryogenic Acoustic Microscopy".

C. F. Quate - Invited talk, Rank Prize Funds International Symposium on "Scanned Image Microscopy", September 22-24, 1980, Royal Society, London, England. Paper entitled "Microwaves, Acoustics and Scanning Microscopy".

Meetings, continued

J. Heiserman - Invited paper, 100th meeting of the Acoustical Society of America, 17-21 November, 1980, Los Angeles, California. Abstract entitled "Acoustic Microscopy at Optical Wavelengths", J. Acoust. Soc. Am. 68, Suppl. 1, B1.

C. F. Quate - Invited talk, Laser '81 Opto-Elektronik Conference, 5th International Congress and International Trade Fair, June 4, 1981, Munich, West Germany. Abstract entitled "Microscopy and Imaging with Acoustics and Photoacoustics".

J. Heiserman - Invited paper, Sixteenth International Conference on Low Temperature Physics (LT-16), August 19-26, 1981, University of California at Los Angeles, California. Paper entitled "Cryogenic Acoustic Microscopy: the Search for Ultrahigh Resolution using Cryogenic Liquids".

D. Rugar - 1981 IEEE Ultrasonics Symposium, October 14-16, 1981, Chicago, Illinois. Abstract entitled "Resolution Improvement in the Acoustic Microscope using High Intensity Focused Beams".

C. F. Quate - Recipient of the 1981 IEEE Morris N. Liebmann Award at the IEEE Ultrasonics Symposium, October 14, 1981, Chicago, Illinois. Citation "For development of an acoustic microscope capable of sub-micron resolution".

C. F. Quate - Invited talk, Surface Science Symposium with the People's Republic of China, sponsored by Xerox PARC, October 20, 1981, Palo Alto, California. Talk entitled "Acoustic and Photoacoustic Microscopy in the Study of the Elastic Properties of Surfaces".

D. Rugar - 103rd Meeting of the Acoustical Society of America, April 26-30, 1982, Chicago, Illinois. Abstract entitled "Theory of Resolution Improvement in a Focused Acoustic Imaging System using High Intensities", J. Acoust. Soc. Am. 71, Suppl. 1, S30.

C. F. Quate - Recipient of the Rank Prize for Opto-Electronics, Royal Institution, London, England, April 27, 1982. Sponsored by the Rank Prize Funds. Awarded in "recognition of his contribution to medical, biological and physical research through the concept of the scanning acoustic microscope, which uses sound rather than light to form images".

Meetings, continued

D. Rugar - Acoustical Imaging '82, Twelfth International Symposium on Acoustical Imaging, London, England, sponsored by IEE/IEEE, 19-22 July, 1982. Abstract by D. Rugar, J. Foster and J. Heiserman entitled "Acoustic Microscopy at Temperatures less than $0.2^{O}K$". (Paper to be published.)

Invited Talks

C. F. Quate - Invited Lecture, Kompfner Lecture Series, Bell Laboratories, Holmdel, New Jersey, May 14, 1979. Abstract entitled "Acoustic Microscopy".

C. F. Quate - Invited Seminar, Max-Planck-Institut fur Festkorperforschung, Stuttgart, West Germany, December 10, 1979. Talk entitled "Acoustic Microscopy at Microwave Frequencies".

C. F. Quate - Invited Colloquium, University of California, Santa Cruz, Department of Natural Science, Santa Cruz, California, April 3, 1980. Talk entitled "A New Form of Microscopy with Acoustic Waves".

C. F. Quate - Invited Colloquium, Princeton University, Department of Physics, February 26, 1981. Abstract entitled "The Acoustic Microscope - a System for Imaging with Microwaves".

C. F. Quate - Invited Talk, College of Engineering, University of Colorado, Boulder, Colorado, March 12, 1981. Abstract entitled "The Acoustic Microscope - a System for Imaging with Microwaves".

C. F. Quate - Visiting Professor, Chevron Oil Field Research Company, La Habra, California, June 16, 1981. Talk entitled "The Acoustic Microscope: a Fundamentally New Instrument for Obtaining Images and Characterizing Materials at the Microscopic Level".

C. F. Quate - Invited Speaker, Naval Postgraduate School, Monterey, California, 23rd October, 1981. Talk entitled "Acoustic Microscopy".

C. F. Quate - Invited Talk, Oxford University, Department of Electrical Science, Oxford, England, April 29, 1982. Talk entitled "Imaging with Scanning and Acoustics".

C. F. Quate - Invited Colloquium, University of California, Davis, Department of Physics, June 1, 1982. Talk entitled "Acoustic Imaging and Microscopy".

Review Articles/Write-ups

SCIENTIFIC AMERICAN, Vol. 239, July 1978, "Microscopy by Ultrasound", pp. 78-84.

SCIENCE, Vol. 201, 22 September, 1978, "Acoustic Microscopy: a New Window to the World of the Small", Thomas H. Maugh II, pp. 1110-1114.

SCIENCE NEWS, Vol. 114, No. 13, September 23, 1978, "Sound Reveals a Hidden Microscopic World", John H. Douglas, p. 219.

A. Atalar, "An Angular-Spectrum Approach to Contrast in Reflection Acoustic Microscopy", J. Appl. Phys. 49, 5130-5139, October 1978.

INDUSTRIAL RESEARCH/DEVELOPMENT, December 1978, "Acoustic Scope has Optical Resolution", p. 35.

PHYSICS TODAY, May 1979, "Scanning Acoustic Microscopy", Bertram Schwarzschild, pp. 20-21.

C. F. Quate, A. Atalar and H. K. Wickramasinghe, "Acoustic Microscopy with Mechanical Scanning - a Review", Proc. IEEE, 67, 1092-1114, August 1979.

C. F. Quate, "The Acoustic Microscope", Scientific American, 241, 62-70, October 1979.

R. A. Lemons and C. F. Quate, "Acoustic Microscopy", in Physical Acoustics, Vol. XIV, W. P. Mason and R. N. Thurston, eds (Academic Press, 1979) pp. 1-92.

INSIDE R&D, Vol. 9, No. 26, June 25, 1980.

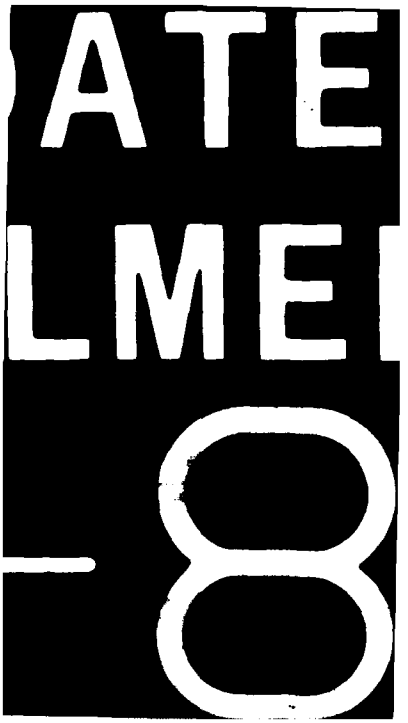
THE NEW YORK TIMES, August 24, 1980, "Microscope Studies Shallow Depths", Walter Sullivan.

Awards

D. Rugar - 1981-82 F. V. Hunt Fellowship in Acoustics, Acoustical Society of America.

C. F. Quate - 1981 IEEE Morris N. Liebmann Award.

C. F. Quate - 1982 Rank Prize for Opto-Electronics.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